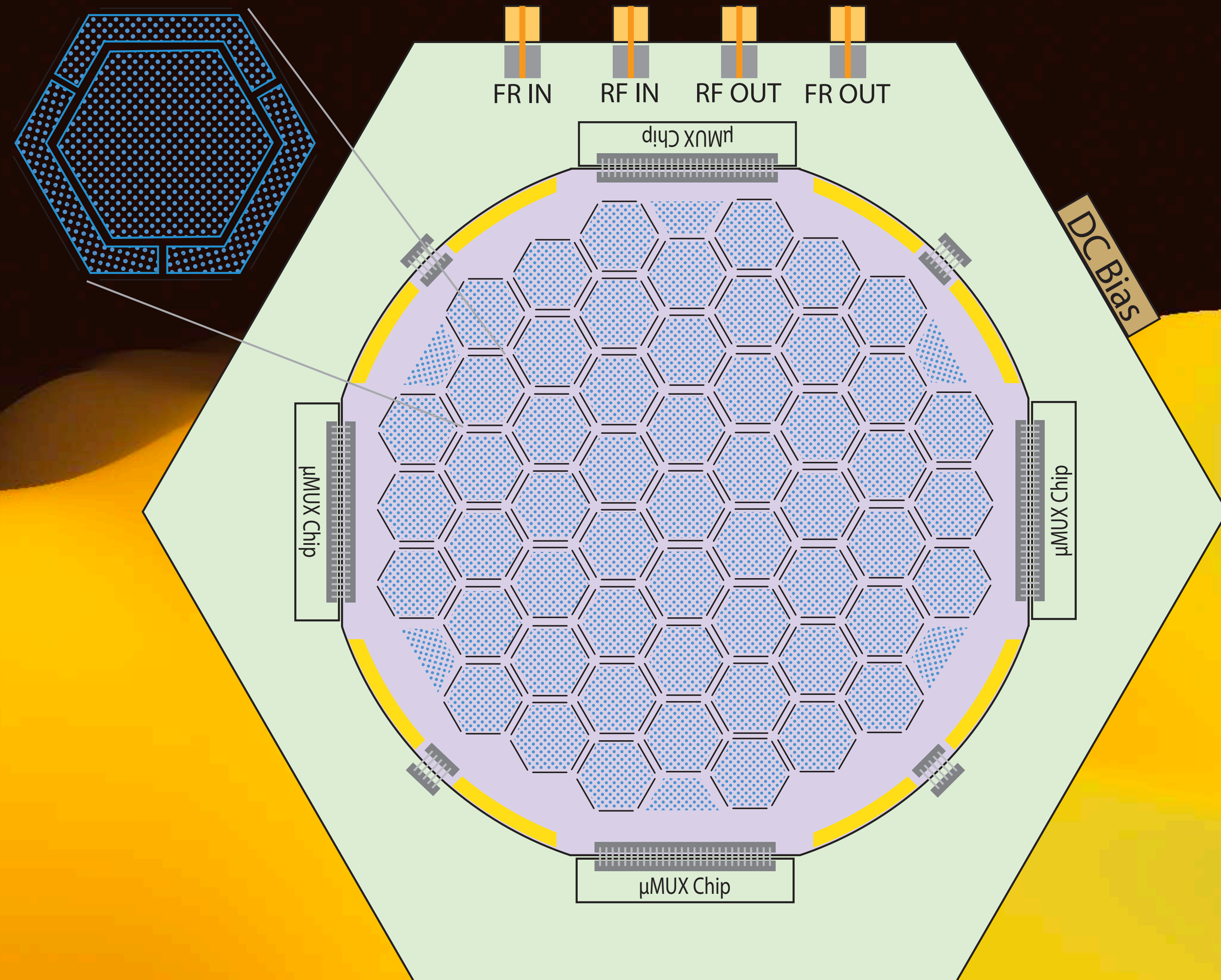


HONEYCOMB

The HOdoscopic Neutrino-EnergY CryOgenic Multiplexed Bolometer

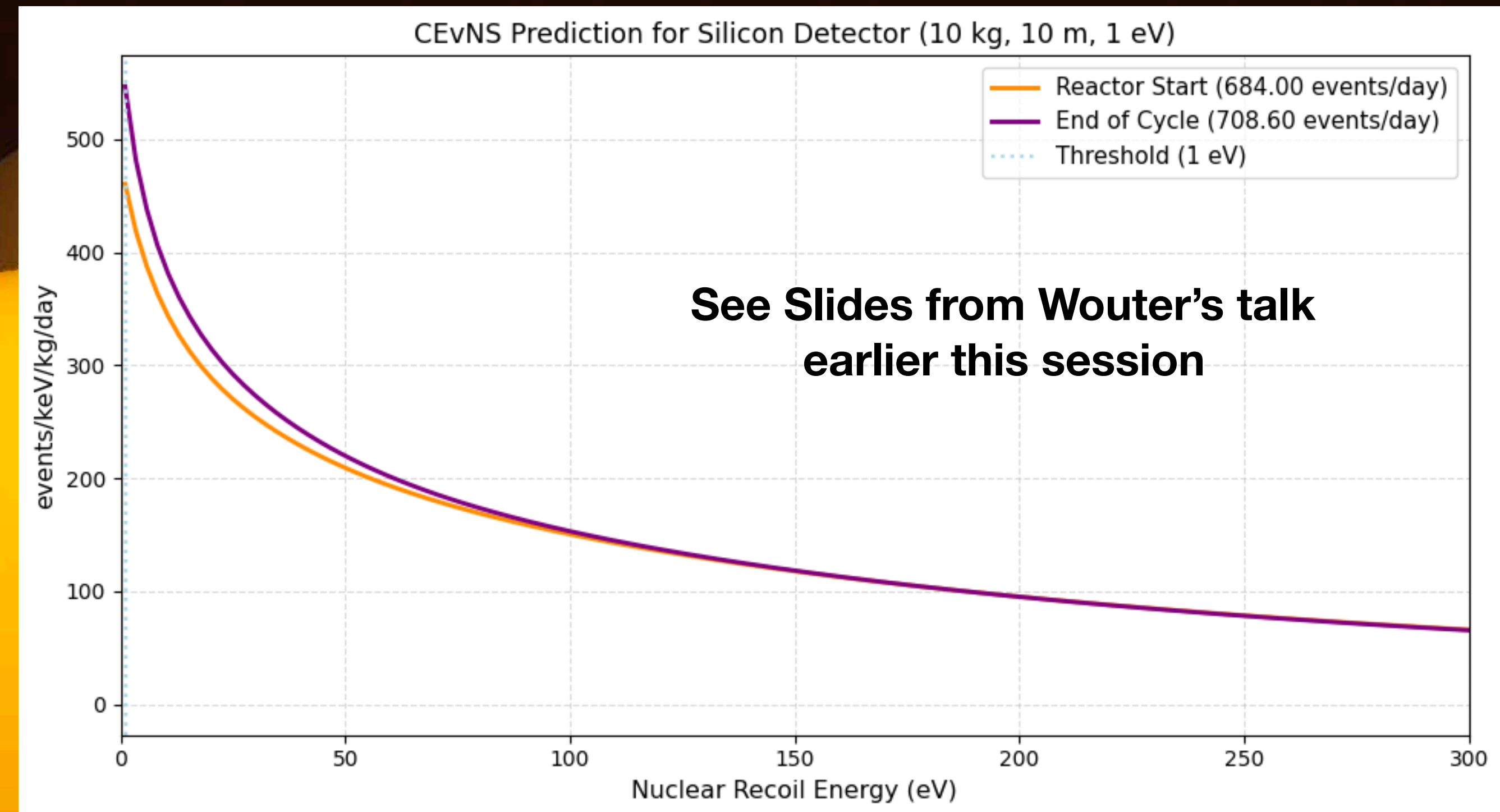
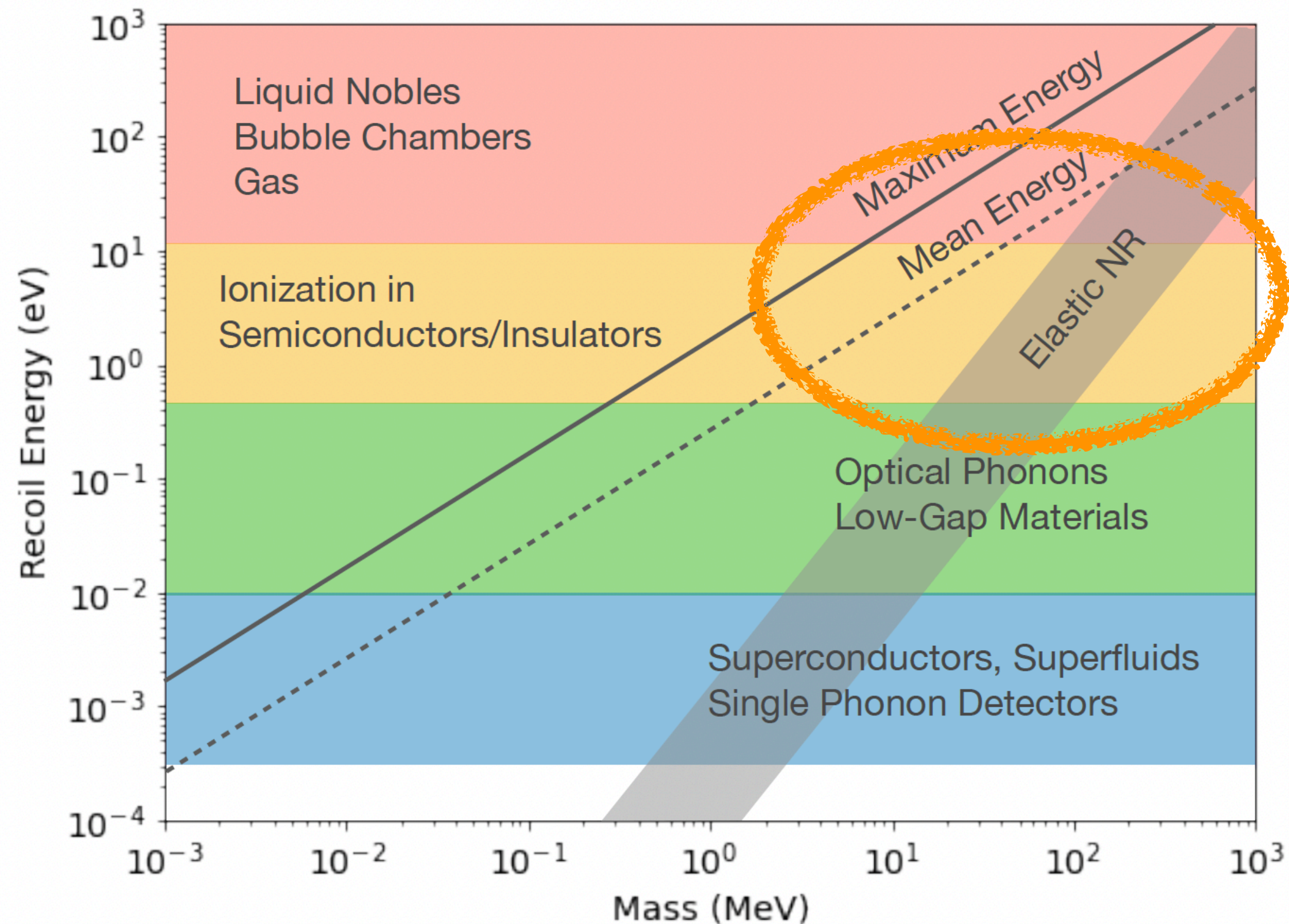
Pratyush Patel on behalf of
Enectali Figueroa-Feliciano
Northwestern University



Target Science: Neutrinos and Dark Matter

- Both want low-threshold O(eV) detectors
- Both want O(kg) mass
- For Dark matter, targets are MeV-GeV particles
- For Neutrinos, CEvNS reactions at nuclear reactors

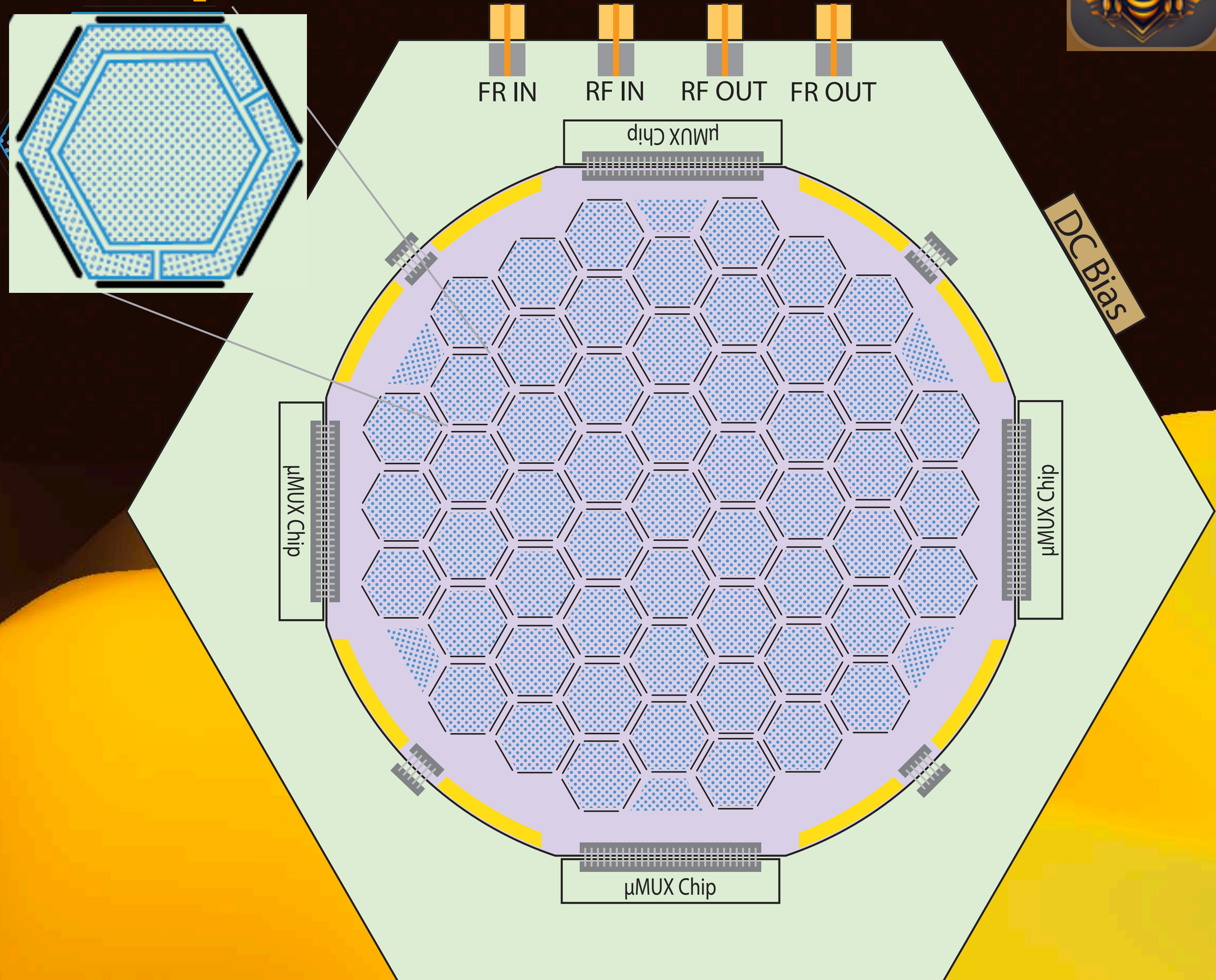
Fig. adapted from 2203.08297



HONEYCOMB Concept



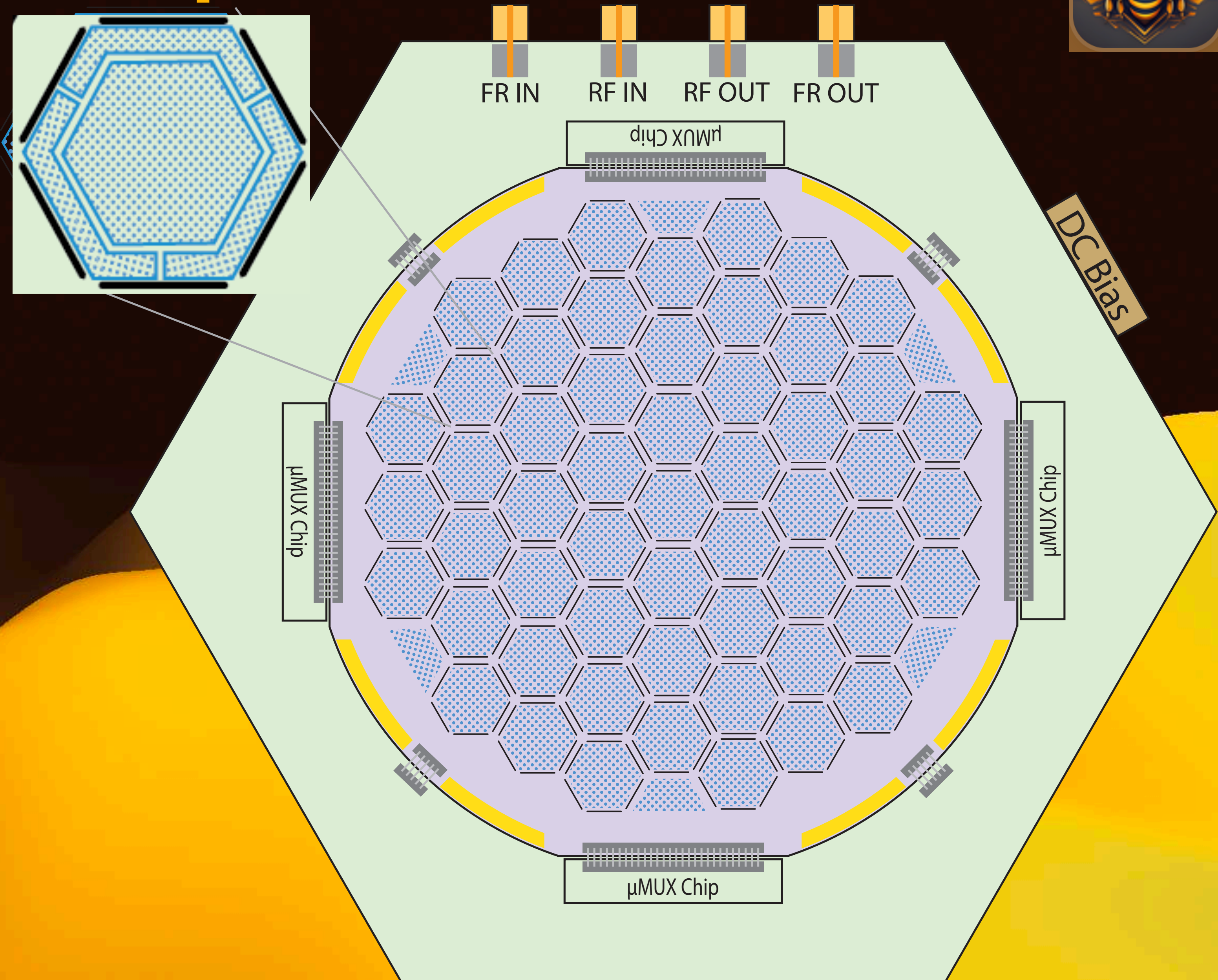
- Small detectors for O(eV) threshold, a few grams each—not tied to a particular technology
- Many detectors on a single wafer, with frames or “streets” between them for thermal conduction, mechanical support, and wiring.
- “Dicing” wafer with Deep Reactive Ion Etching trenches on the front + Laser Dicing on the back. A final acid etching smoothes sidewall roughness
- Leave a small “bridge” for thermal conduction, mechanical support, and electrical connection



HONEYCOMB Concept

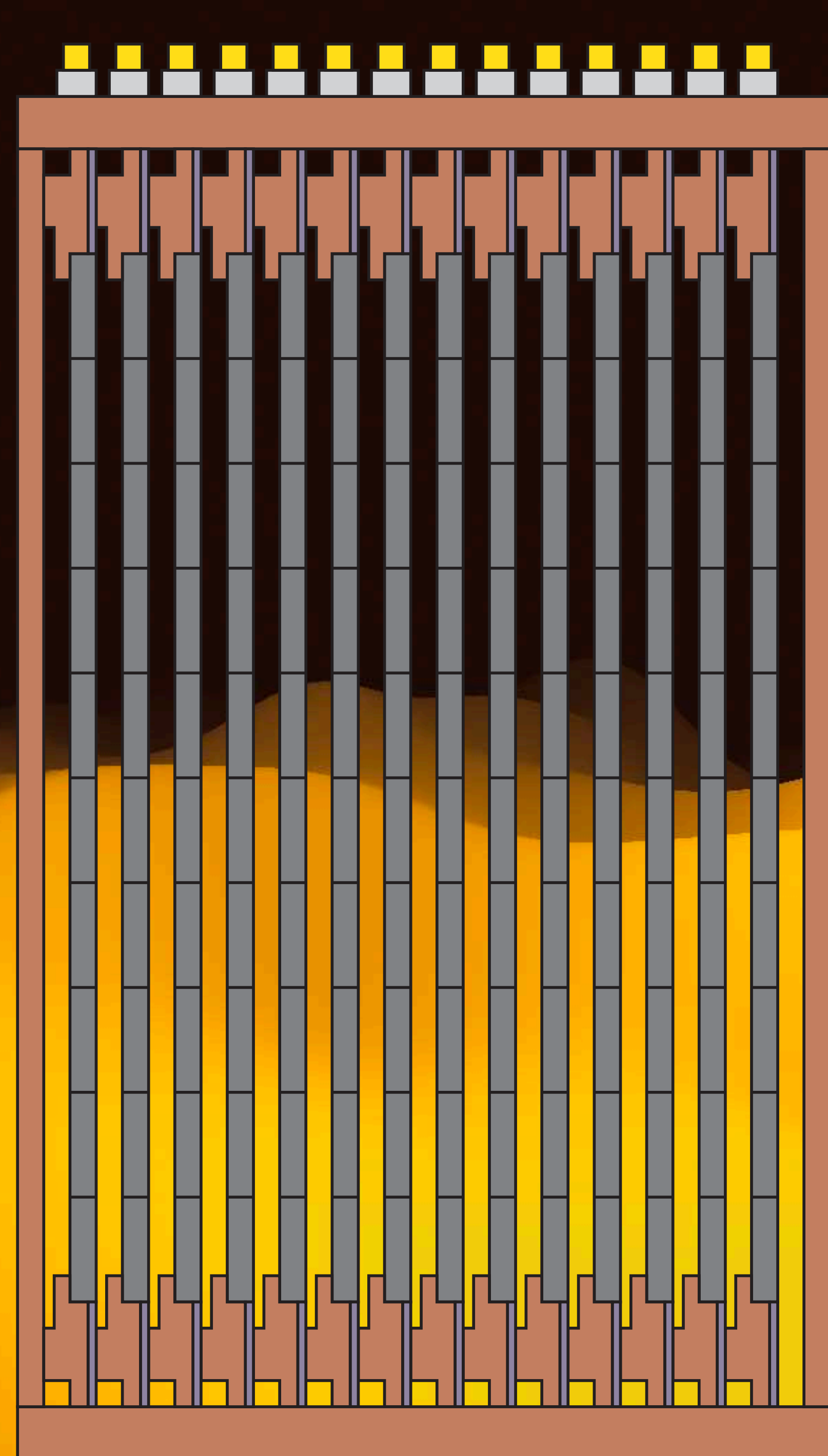


- Frames are also instrumented for veto purposes
- Stress-free mounting, hope to reduce low energy excess
- Heavy use of RF Multiplexing
 - Could be NIST μ MUX for TES
 - Or QICK or SMURF for MKIDS / Qubits



HONEYCOMB Concept

- Stacking multiple wafers for O(kg) payload units
- High-detector count serves as active veto for each other (Hodoscope)
- One example with multiplexed readout of 3000+ channels:
 - 55 detectors per Ge wafer, 1.5 g each
 - 14 wafers, 770 detectors, 1kg mass
 - 4 channels per detector
 - Other channels on frames for vetos



GEANT4 Simulation

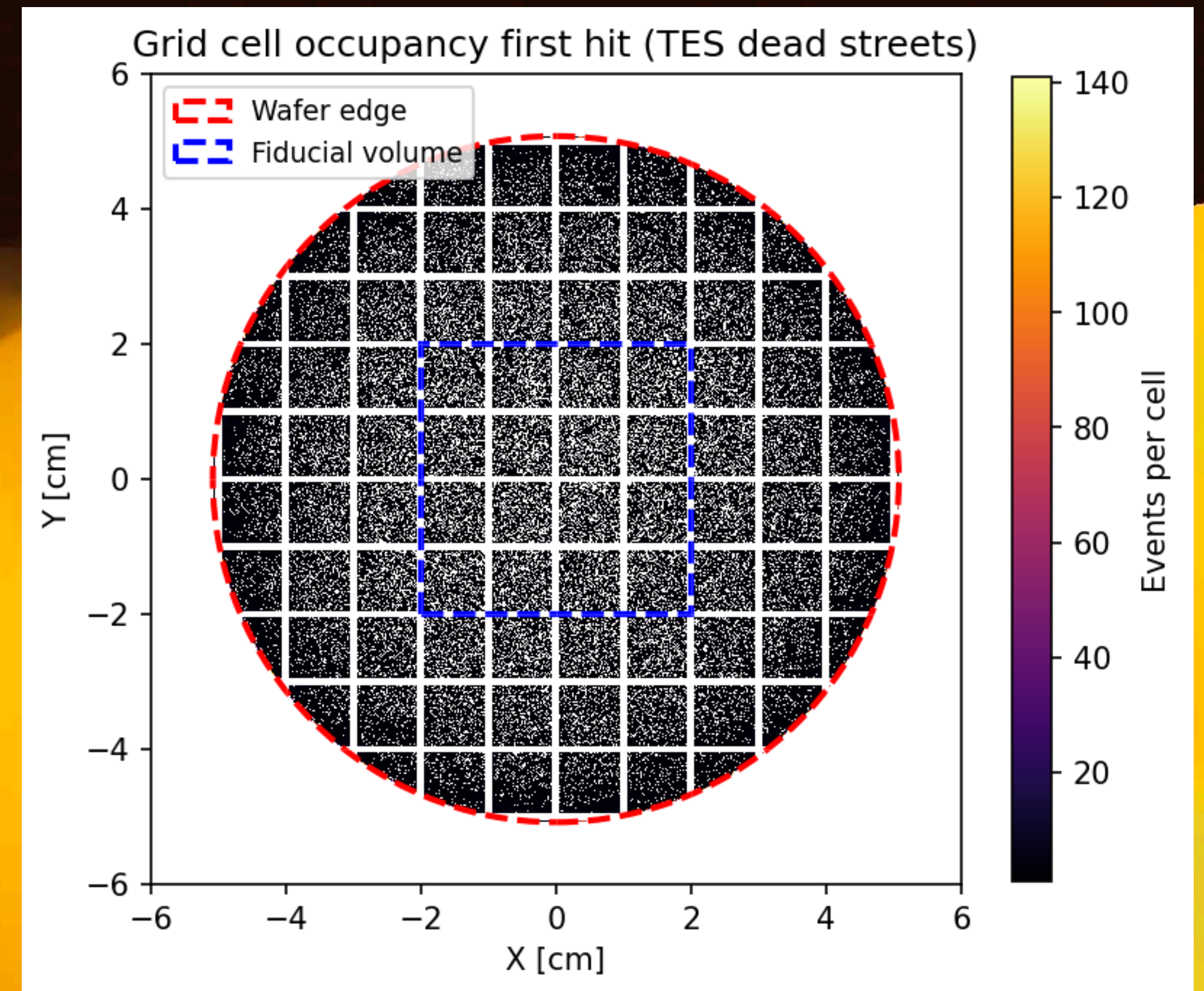
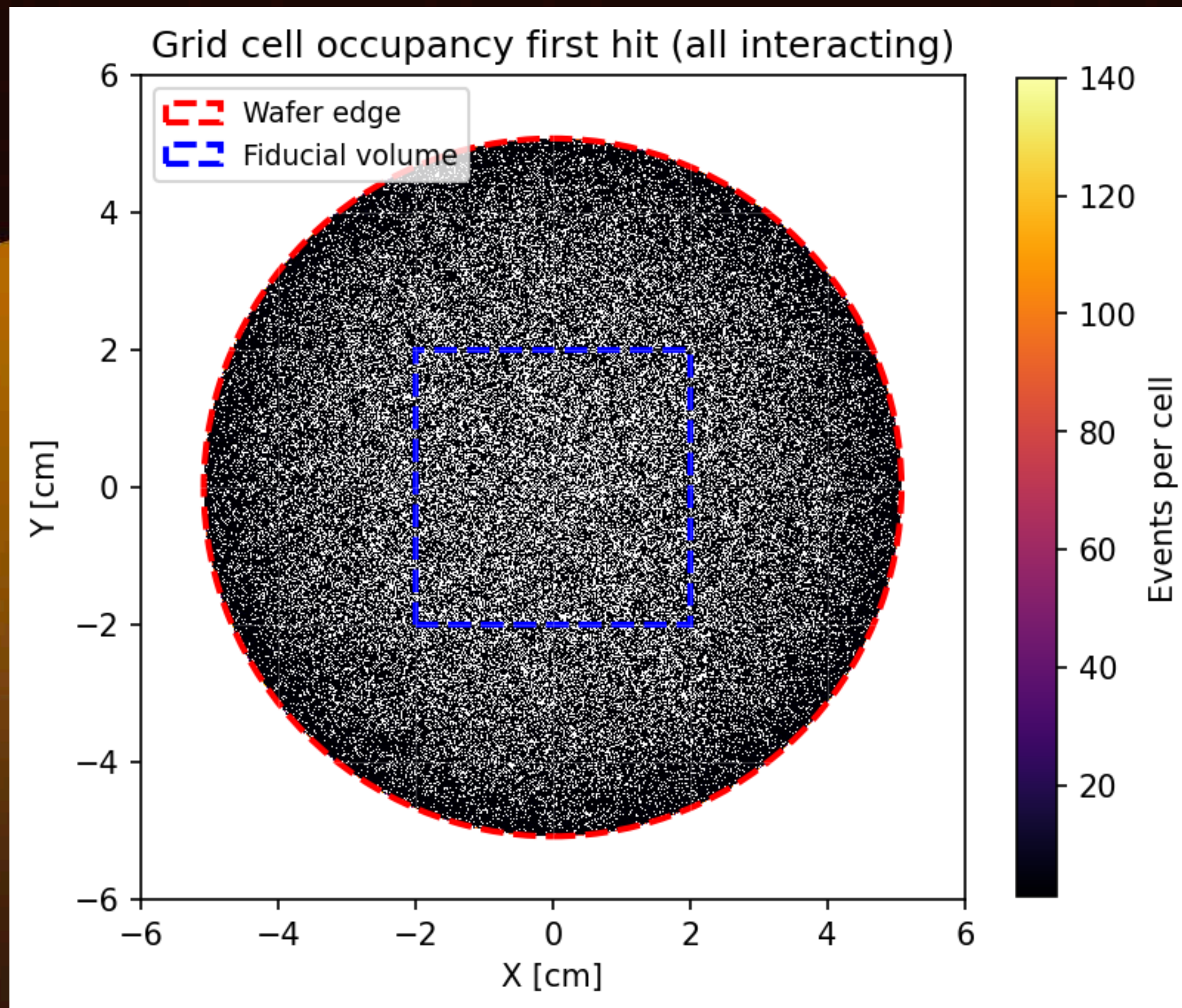
- Trying to answer the question: Can we reduce backgrounds?
- Work by Hussein David, Cheyanne Monk, Miriam Diamond, Ziqing Hong at U. Toronto
- Geometry: 25 wafer stack surrounded by a copper box
- Simulated Ge wafers with both gamma and neutron sources
- 100mm diameter Ge wafers, 4mm thick
- 10M Ba-133 gammas
- 100M Cf-252 for neutrons

Work In Progress!



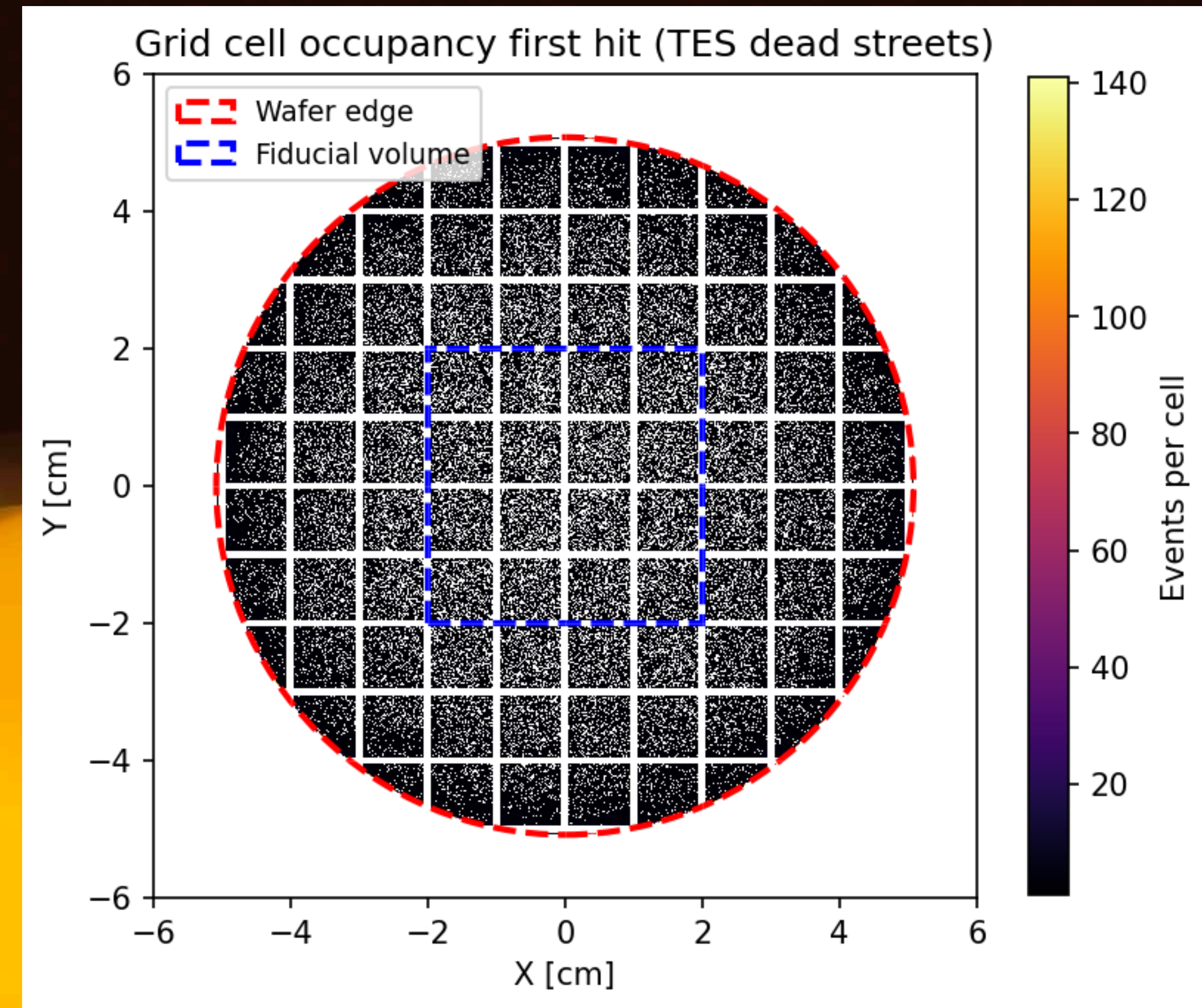
GEANT4 Simulation

- To simplify geometry, simulated solid wafers. Detector pixelation done in analysis.
- To simplify analysis, used a square geometry of 1cm detectors with 1mm frame
- Also looked at defining a fiducial volume of the inner 4x4 detectors

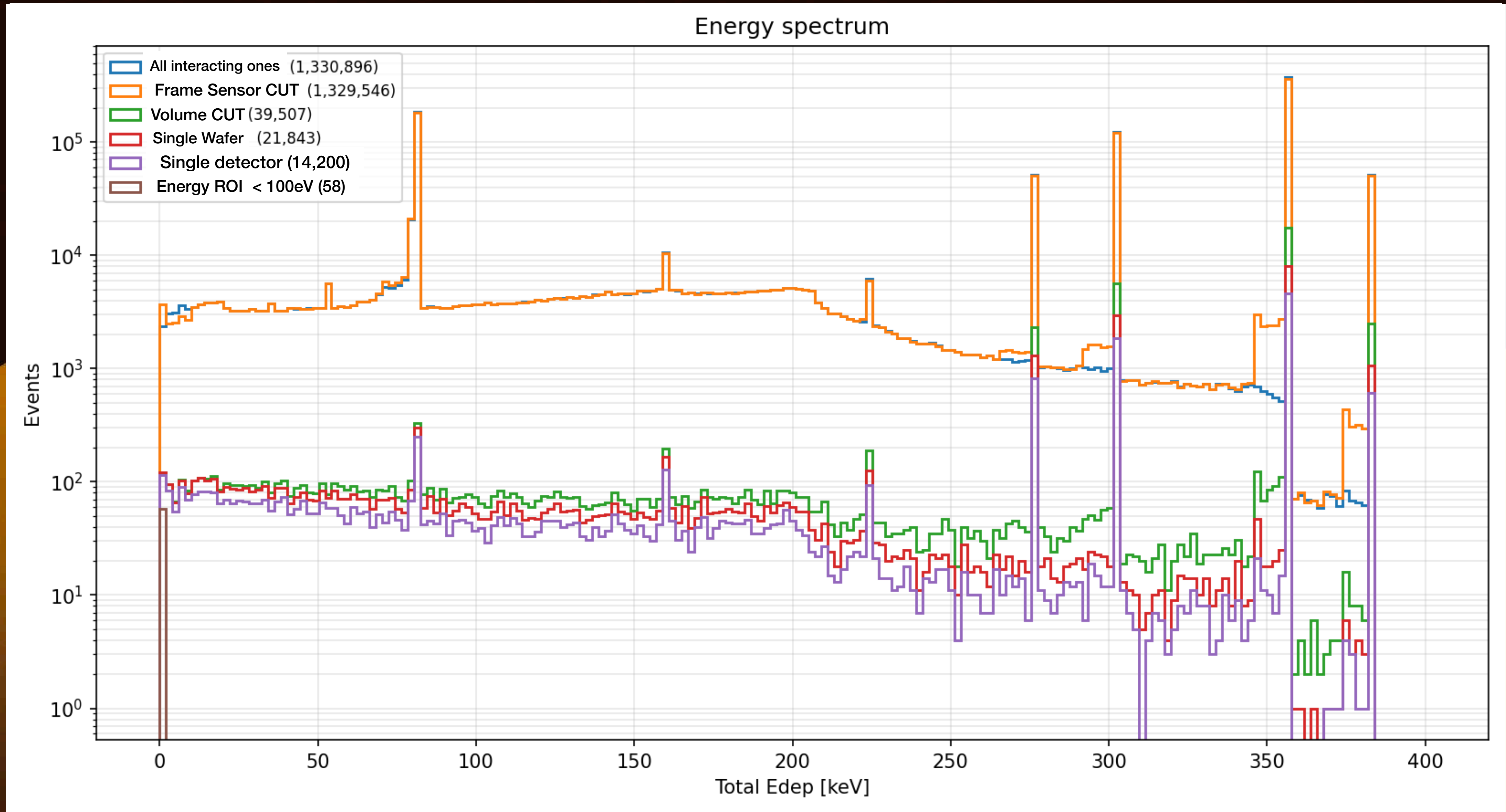


GEANT4 Simulation: Cuts

- Simulation consisted of 10/100M events emanating inward from a sphere surrounding the detector wafer stack, which was surrounded by a Cu box.
- Only about 13% of the events passed through the wafers. We measure how many events pass different cuts starting from this number.
 - How many of these interact (deposit energy) in a wafer
 - How many deposit $>1\text{eV}$ (assumed threshold in detector)
 - How many deposit $>10\text{keV}$ in frames (assumed frame threshold)
 - How many hit only inside the fiducial volume (inner 4x4 and not the top or bottom wafer)
 - How many hit just one wafer
 - How many hit just one detector
 - How many deposited $<100\text{ eV}$ (ROI cut)



GEANT4 Simulation: Ba-133 gammas

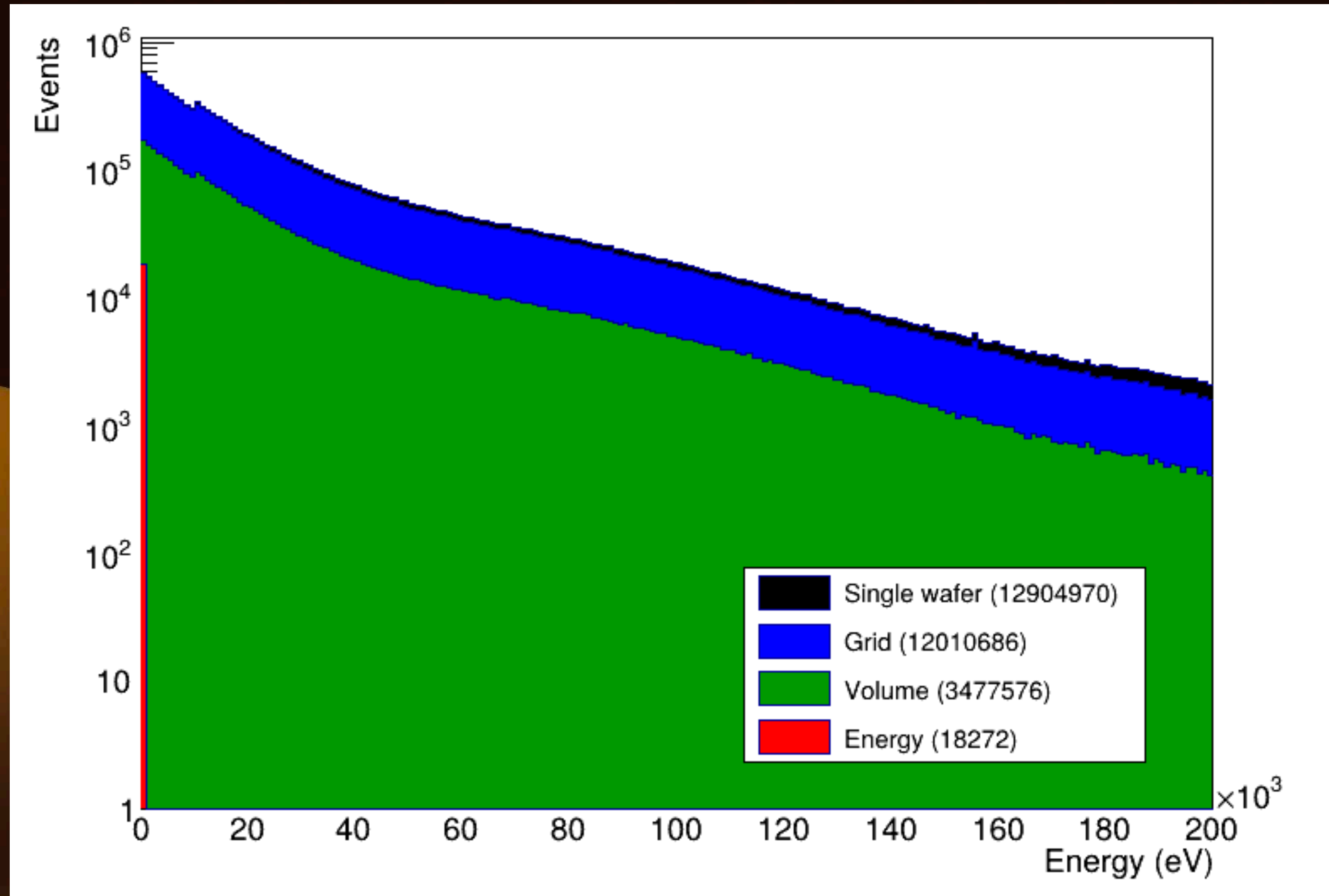


GEANT4 Simulation: Ba-133 gammas

Takeaway: Very good rejection of gamma backgrounds, but most of it comes from the energy cut ($\text{ROI} < 100 \text{ eV}$). Geometry can give you a factor of a few. Full system removes around 99.9% of all gammas in ROI.

Stage	Full stack		Fiducial	
	Events	Surv. [%]	Events	Surv. [%]
Simulated	10,000,000			
Interacting	1,456,793	100.0	183,620	100.0
Single wafer	825,193	56.64	87,994	47.92
Single Detector	538,139	36.94	53,620	29.20
ROI ($E < 100 \text{ eV}$)	1,405	0.0964	187	0.1018

GEANT4 Simulation: Cf-252 neutrons



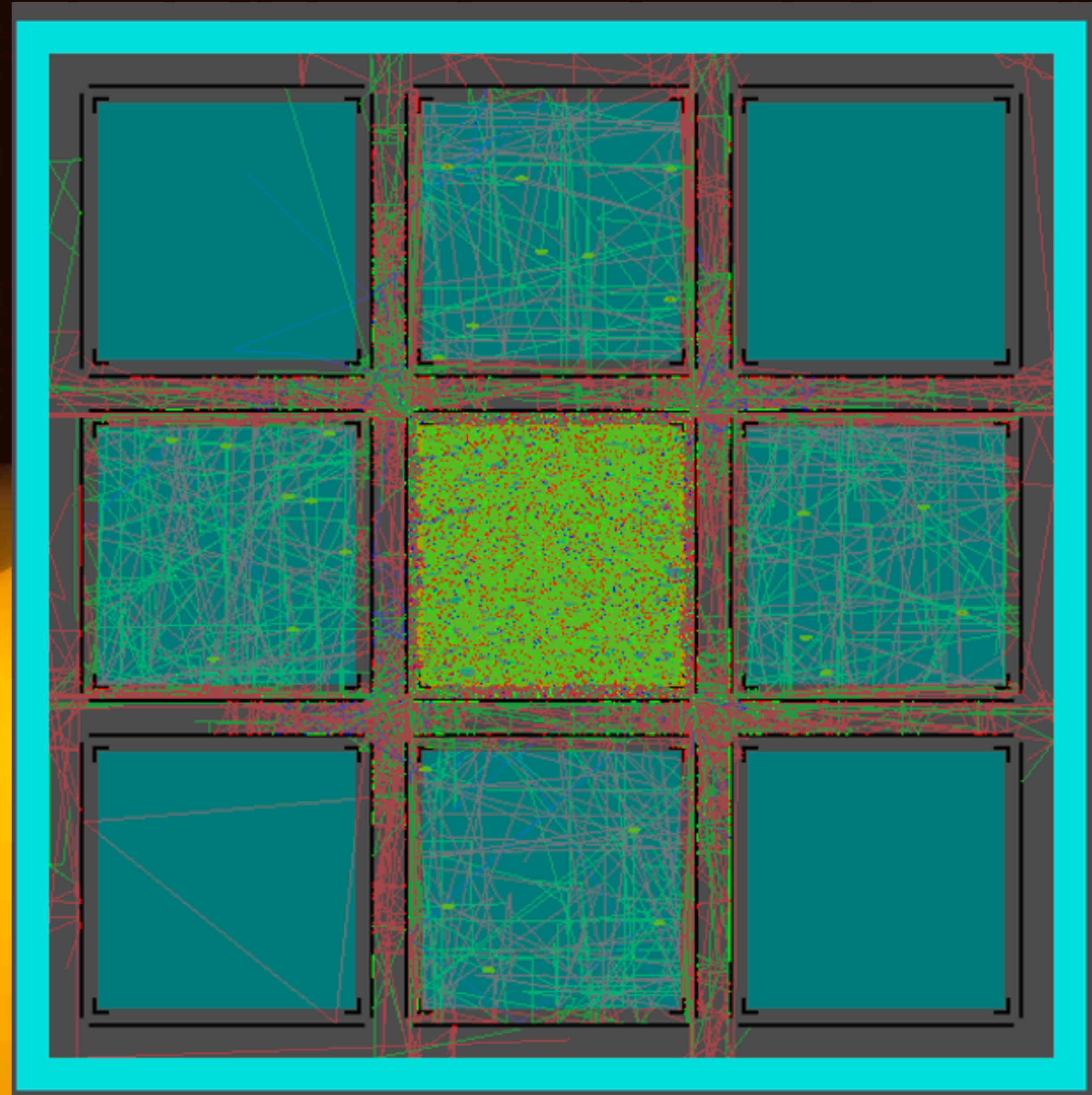
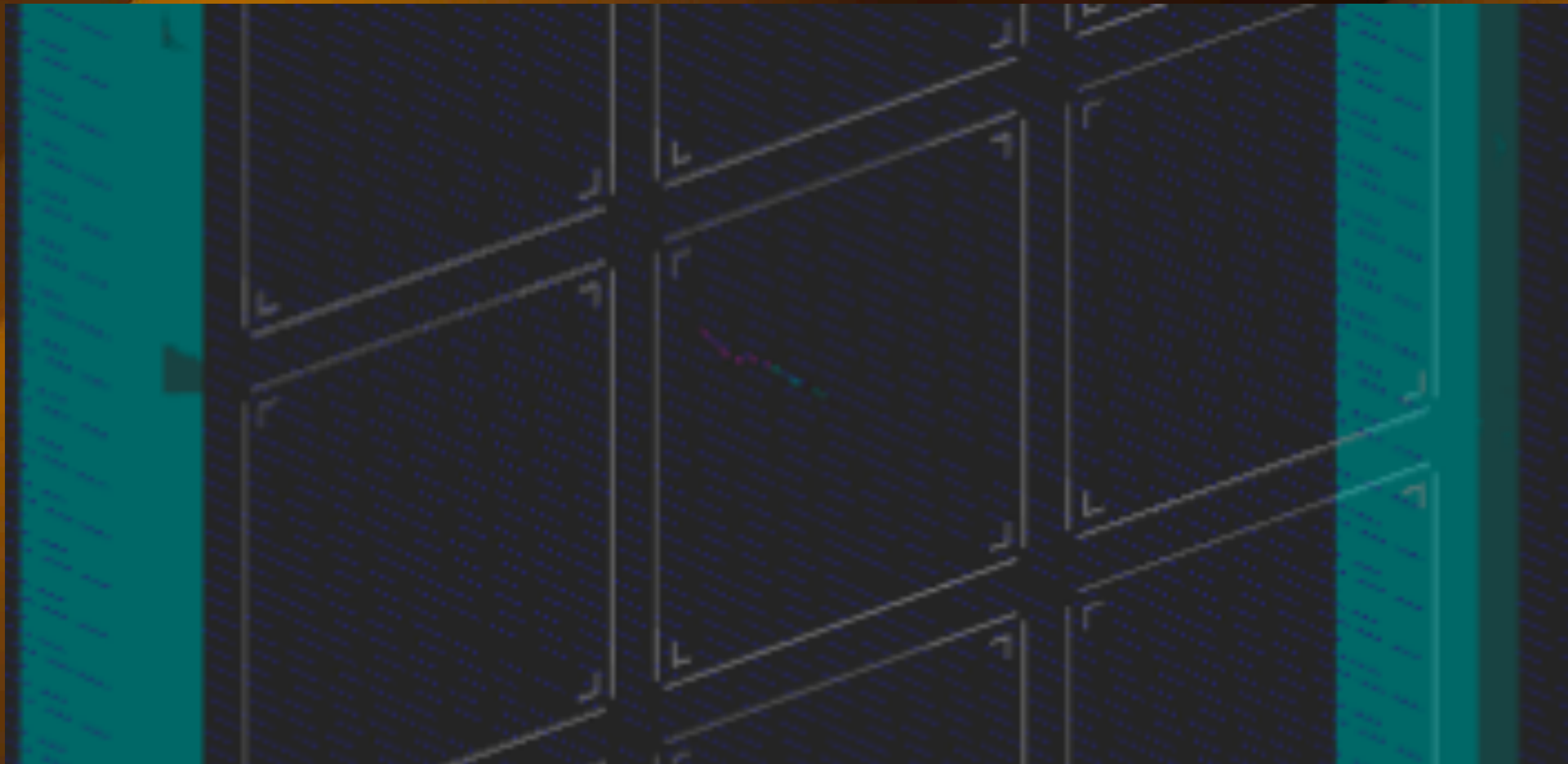
GEANT4 Simulation: Cf-252 neutrons

Takeaway: Same story. Good rejection of neutron backgrounds, but most of it comes from the energy cut ($\text{ROI} < 100 \text{ eV}$). Geometry can give you a factor of a few. Full system removes around 99.7% of all neutrons in ROI.

Stage	Events (Total)	Survival[%] (Total)	Events (Fiducial)	Survival[%] (Fiducial)
MC Generated	1×10^8			
Interacting	2.74×10^7	100	6.25×10^6	100
Single Wafer	1.29×10^7	47.1	3.67×10^6	58.7
Single Detector	1.20×10^7	43.8	3.48×10^6	55.6
ROI ($E < 100 \text{ eV}$)	6.05×10^4	0.22	1.83×10^4	0.29

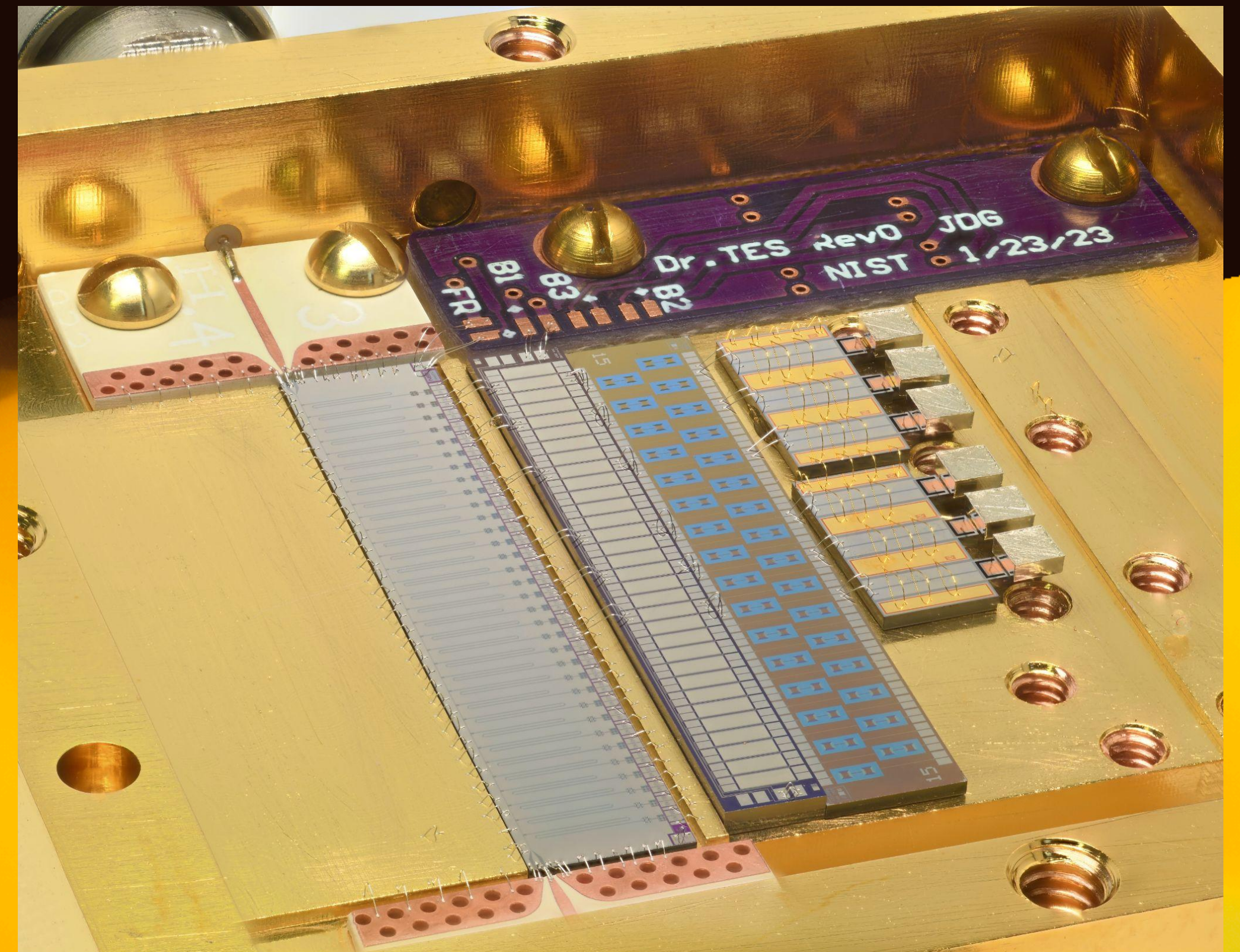
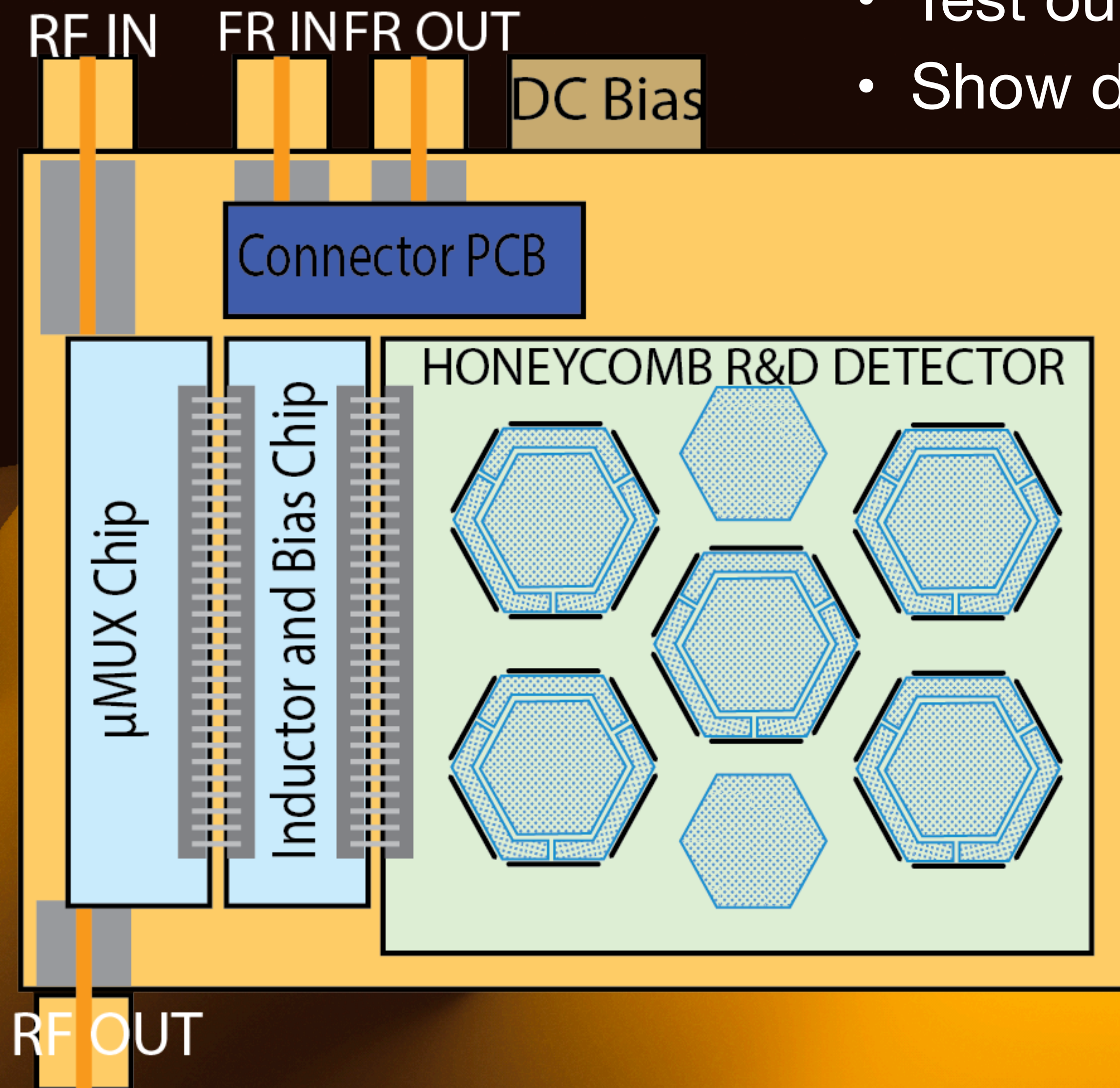
G4CMP Simulations (in progress)

- Trying to answer the question: How do we optimize the DRIE cuts to maximize detector phonon collection and minimize phonon crosstalk?
- Work by Iffat Zarif at Northwestern
- Started with same square geometry as GEANT4 sim, will move both to hexagons next.



HONEYCOMB Prototype (still a proposal)

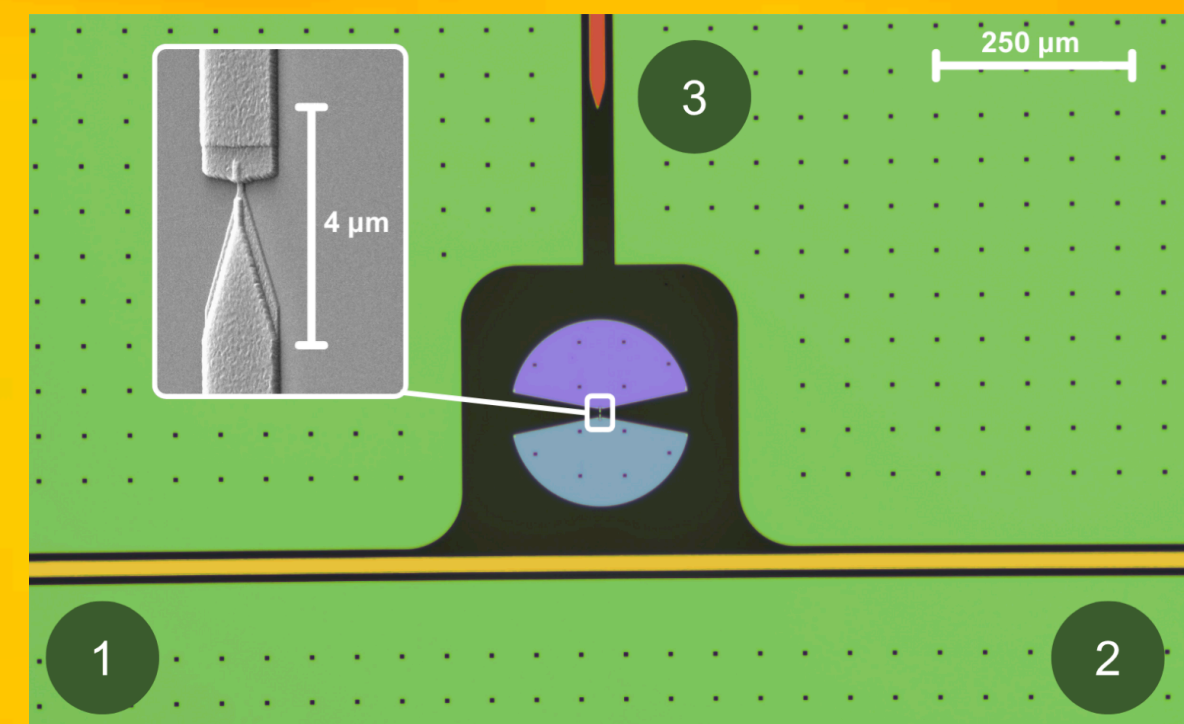
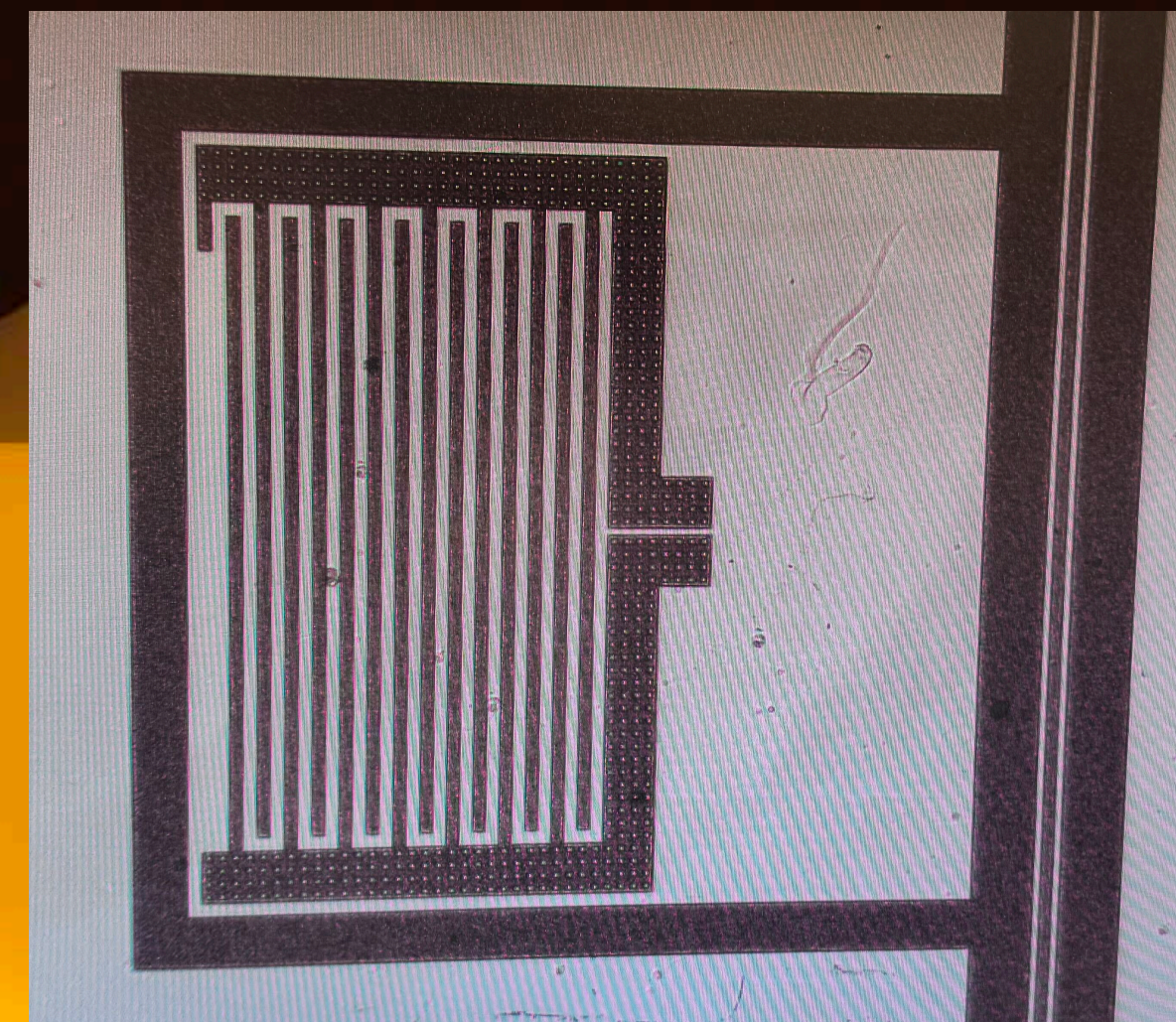
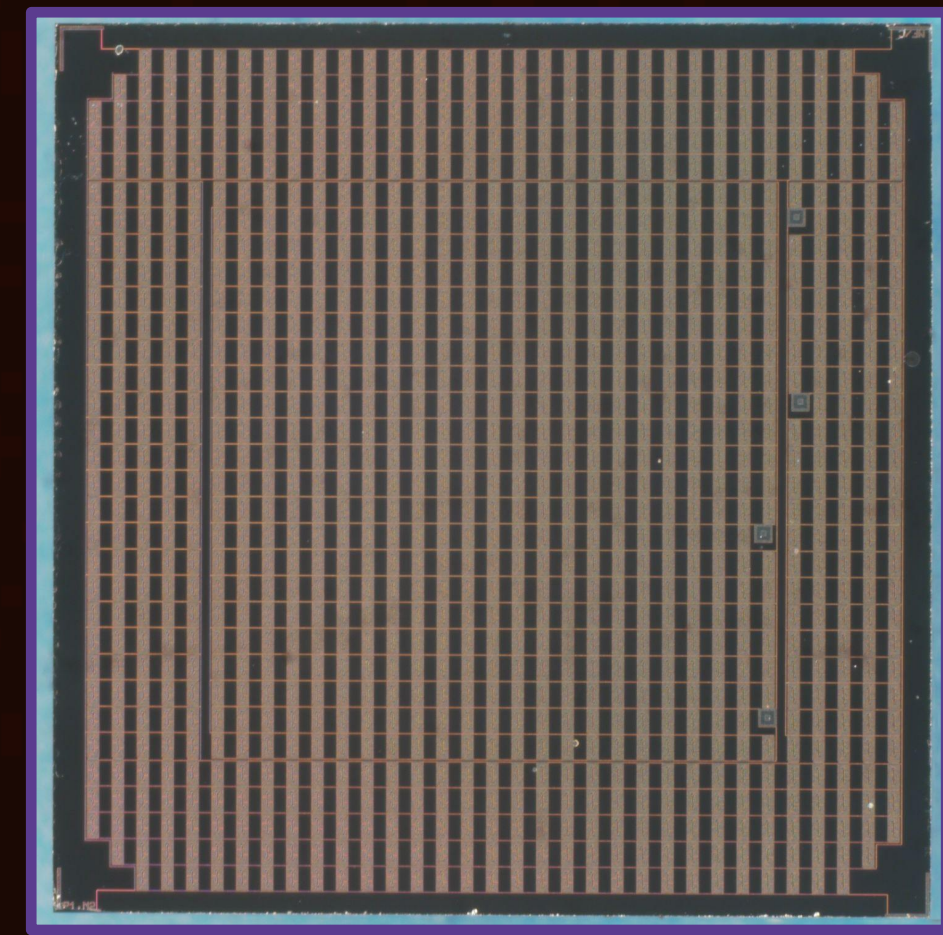
- Will use NIST μ MUX TES readout
- Test out fabrication, integration, μ MUX
- Show device performance — ready for scaling



Pronghorn Gamma Ray Prototype
(image from NIST)

A word on Detectors

- So far, none of the previous slides have assumed a particular detector technology. The HONEYCOMB concept is primarily a way to fabricate, package, and read out many small detectors using RF readout.
- The actual detectors could be:
 - SuperCDMS HVeV detectors
 - MKID detectors (like BULLKID)
 - SQUAT quantum detectors (see Riley Carpenter's talk Wed)
 - Or a combination of these!



Conclusion

- Honeycomb seeks to field O(eV) threshold detectors at scale for neutrino and DM experiments.
- GEANT simulations are studying the background rejection of large arrays of detectors.
- G4CMP modeling is underway to optimize the DRIE trenches between pixels to minimize crosstalk.
- Studying TES, MKID, and SQUAT detector implementations.

